Firmware Library

A firmware library is a ready-made helper code that knows how to talk to hardware for you.

Instead of you controlling hardware *bit by bit*, the library gives you **easy function**

What Happens when you Power VSD Squadron Mini Board ?

Step 1: Power reaches the microcontroller

- Transistors inside become active
- Clock oscillator starts ticking ⏱️

Step 2: Reset circuit triggers

The chip enters a known state.

Step 3: Program Counter (PC) starts

The CPU does:

PC = 0x0000

Step 4: CPU reads Flash memory

It fetches the **first instruction** of firmware.

👉 This is where firmware comes into play.

Step 5: Instruction → Execute → Repeat

This loop never stops:

Fetch → Decode → Execute

All calculations and signals come from:
✓ Electricity
✓ Controlled by **firmware instructions**

Goal of this Notes:

1. Understand what a firmware is ?
2. What are firmware libraries and why is it required ?

Firmware

What is *firmware*?

Firmware is the **software that runs directly on hardware**.

- Runs on microcontrollers (Arduino, ESP32, STM32, etc.)
- Controls **pins, sensors, motors, communication**
- Lives *between hardware and your application logic*

What do you mean by “BETWEEEN”? Is it physically between ? or is the logically between or between the code lines ?

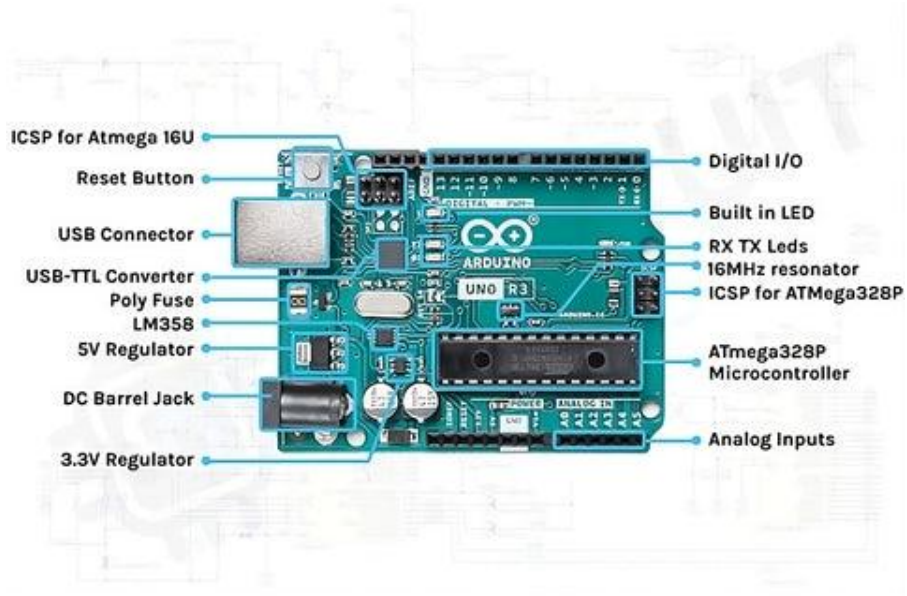
At the end of the day whatever wherever the code is… it should help us control the hardware. Also we know that, Software – is set of instructions

Therefore, Firmware is a set of instructions that directly runs on hardware.

Hardware ? you mean registers, capacitors, transistors ?

No Firmware is run by the Microcontroller’s CPU unit which in-turn produces signals which uses other parts of the PCB such as registers, capacitors, resisters etc…

Control the hardware? How can you control the hardware?
Lets take a simple example of Arudino UNO and understand this



Let’s start our story from the time the Arduino Board gets the electricity . Because that is where the Hardware gets its LIFE isn’t it ??

Step 1: Powering the board

What happens when you power an Arduino board?

YES — electricity flows to:

- Voltage regulator , Capacitors, Resistors, LEDs
- Microcontroller (ATmega328P on Arduino Uno or CH32 in case of VSD)

All components that are connected to the board **do get powered**.

UNDERSTAND: Electricity alone does NOT create behaviour.
Electricity only **ENABLES** behaviour

(Its not like a light bulb, if I turn the switch ON the light bulb brightens. Yes the thinking is correct but light BULB is a Passive hardware - No decision-making, No logic, No memory, No timing)

Behaviour is fixed by physics

Power ON → Light ON

Power OFF → Light OFF

That's it.

Arduino is NOT like a bulb

Arduino contains a **microcontroller**.

A microcontroller is:

- A tiny computer
- With memory
- With logic
- With a clock
- With decision-making ability

Thing	**Role**
Electricity	Enables operation
Microcontroller	Executes logic
Firmware	Defines behavior

But here's the **critical truth**:

A microcontroller does NOTHING useful unless it is told **what to do.**

Application Code – "Tells WHAT to do?"
Firmware – "Tells HOW to do it using the hardware we currently have?"

Step 2: Microcontroller wakes up

The ATmega328P:

- Receives 5V
- Clock starts ticking (16 MHz)
- CPU comes out of reset

OK now the CPU is alive as it got its electricity. It's only PURPOSE OF LIFE is to serve the almighty so when its alive it asks for INSTRUCTIONS – "What should I do ? What instructions should I execute? "

SO now Who is that Almighty which gives the CPU or the Microcontroller its Instruction ?

The thing is, the Instructions is already written in a memory called FLASH memory which is present inside the Microcontroller.

Where does it get instructions from?

From firmware stored inside it

Inside the microcontroller is:

- **Flash memory** → stores firmware
- **SRAM** → variables
- **EEPROM** → saved data

The firmware is NOT in resistors or capacitors
he firmware is stored **inside the microcontroller chip itself**

Then why doesn't the board "do something" automatically?

Because **hardware by itself is dumb**.

Example:

- A resistor only resists current
- A capacitor only stores charge
- A transistor only switches
- A microcontroller is just **silicon gates**

⚡ Without instructions:

- No blinking
- No calculations
- No decisions

What makes the Arduino “think”?

👉 **Firmware**

What exactly is firmware (physically)?

Firmware is:

- **Binary machine code**
- Stored in **non-volatile memory (Flash)**
- Inside the **microcontroller**

🧭 Where does Arduino firmware come from?

You write:

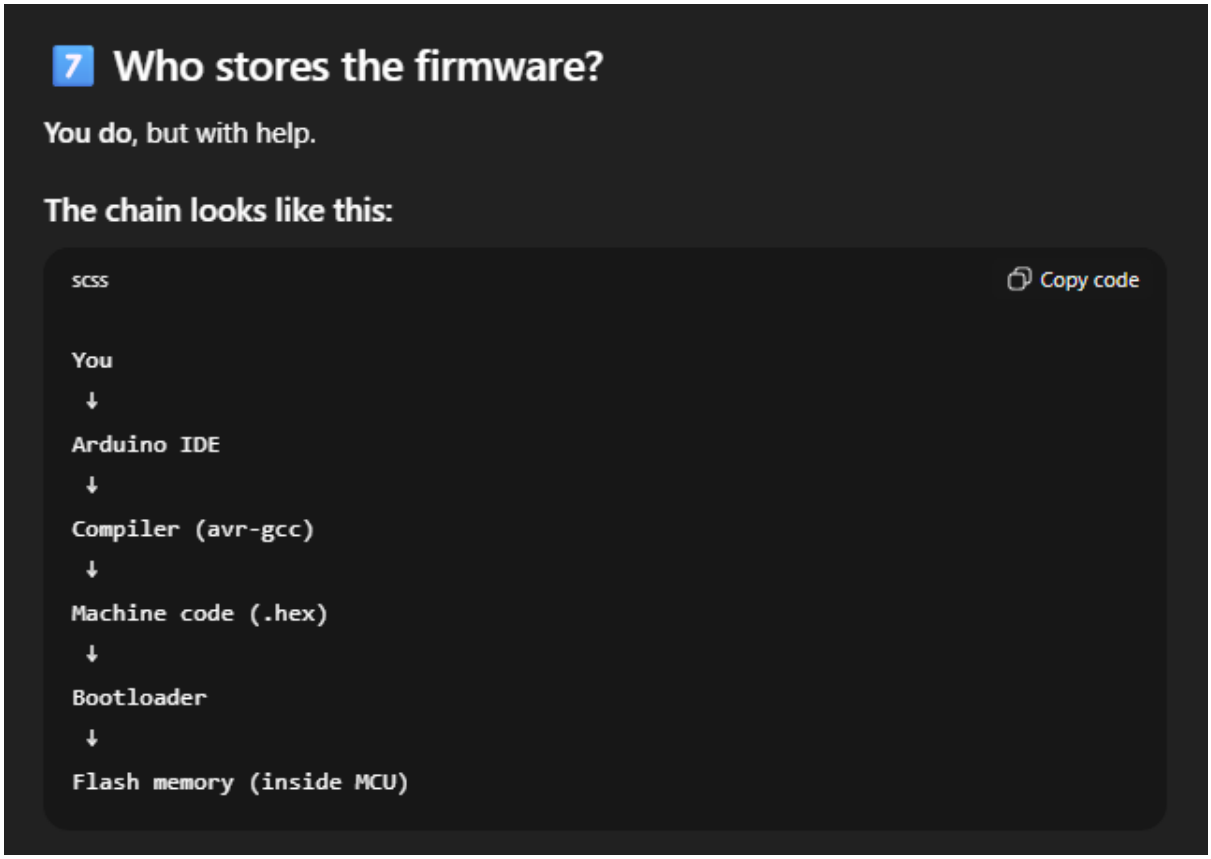
digitalWrite(13, HIGH);

This becomes:

- C++ code
- Compiled to machine code
- Uploaded via USB

Stored in:

📦 **Flash memory inside ATmega328P**



8 What is the bootloader?

The bootloader is:

- A **tiny firmware**
- Pre-installed at the factory
- Lives in a protected Flash area

Its job:

- Listen on USB/Serial
- Accept new firmware
- Write it into Flash

After upload:
➞ Bootloader jumps to **your firmware**

How does Firmware RUN ?

1. Power ON
2. Bootloader runs
3. Bootloader hands control to your firmware
4. setup() runs
5. Loop() runs forever

Where do firmware libraries come in?

Let's say you write:

digitalWrite(13, HIGH);

This is NOT magic.

Under the hood:

digitalWrite()

└── Arduino core firmware library

└── Sets specific MCU register bits

└── Electrical signal appears on pin

👉 Firmware libraries:

- Translate **human-friendly functions**
- Into **hardware register operations**

1️⃣1️⃣ Why don't we write registers directly?

You *can*:

PORTB |= (1 << 5);

But firmware libraries:

- Prevent mistakes
- Handle timing
- Work across boards
- Save time

Electricity: Enables the hardware

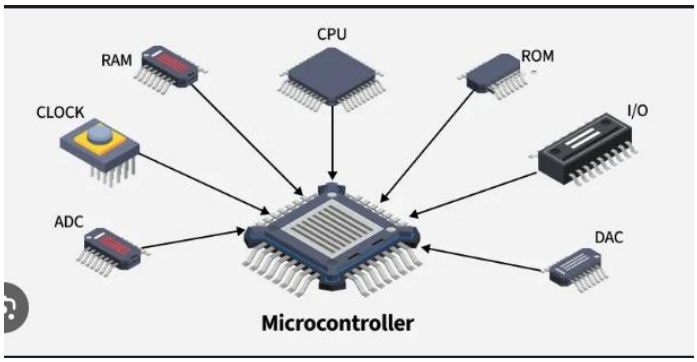
Microcontroller: Executes instructions

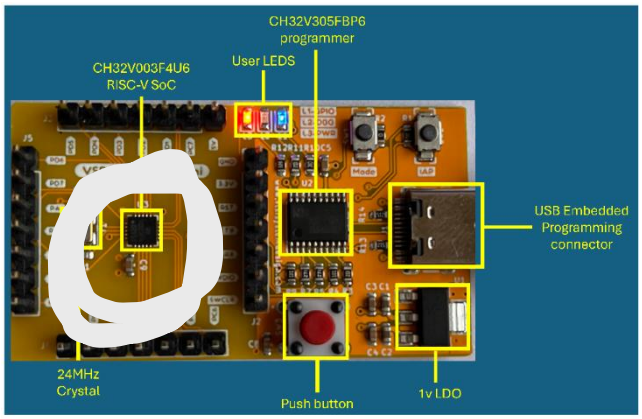
Firmware: Instructions stored in Flash

Firmware libraries: Reusable code that controls hardware safely

What is a microcontroller?

A microcontroller unit (MCU) is essentially a small computer on a single chip. It is not just a computing unit it is the whole computer. But it doesn't need an OS to operate.





1. **Central Processing Unit (CPU)**: Acts as the brain of the microcontroller, executing instructions and performing calculations.

2. **Memory**: Stores data and instructions for the CPU to access.
   i) **Flash Memory**: Non-volatile memory used for storing the program code.
   This is where the Firmware is Present.

   ii) **SRAM (Static Random Access Memory)**: Volatile memory used for temporary data storage.

   Example: A microcontroller might have 256KB of flash memory and 64KB of SRAM.

3. **Input/Output (I/O) Ports**: Allow the microcontroller to communicate with external devices.

4. **Peripherals**: Additional hardware components that extend the microcontroller's functionality.
5. **Power Management**: Components that manage the power supply to the microcontroller

6. **Clock**: Provides a timing signal that synchronizes the operation of the CPU and other components.

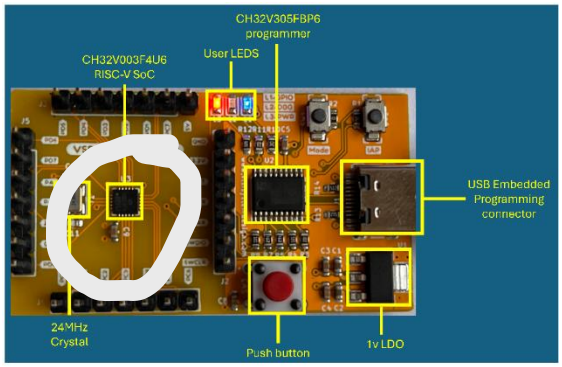
Flash Memory

What is flash memory *physically*?

Flash memory is made of **floating-gate transistors**.

Each bit:

- Stores **charge trapped inside silicon**
- Keeps data **even when power is OFF**



Inside the microcontroller, flash is just a **big linear array**.

Flash is a Non-Volatile Memory and is present inside the microprocessor

How flash is divided internally ?

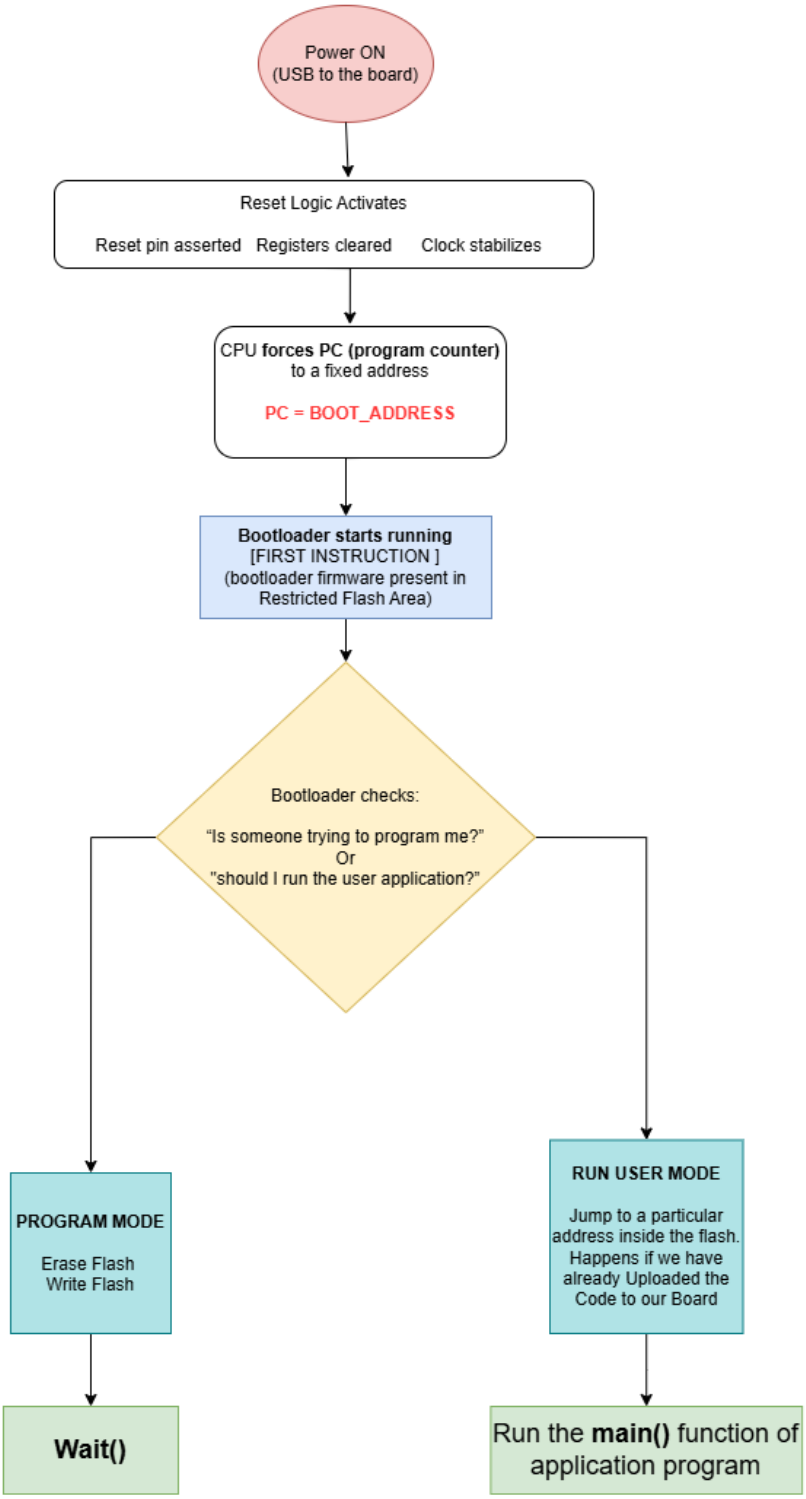
Typical layout on the VSD Squadron Mini looks like this (simplified):

vbnet Copy code

```
┌──────────────────────────────┐
| Bootloader (RESTRICTED)      |  ← protected region
| ~1.9 KB                      |
├──────────────────────────────┤
| User Application Flash       |  ← your code
| ~14 KB                       |
├──────────────────────────────┤
| (Optional config / option bytes)
└──────────────────────────────┘
```

The restricted part of flash memory permanently stores the Bootloader, which is the very first code the CPU executes after reset, and hardware protection prevents your application from overwriting it.

What happens when power is applied?



RISC-V

RISC-V is an instruction set architecture (ISA).

It basically defines what instructions the CPU understands. Think of it like a language. We humans understand English, CPU understand RISC-V instructions.

What is ISA?

A set of instructions the CPU understands

Instruction	**Meaning**
ADD	Add two registers
SUB	Subtract
LOAD	Read memory
STORE	Write memory
JUMP	Change execution flow

If an instruction is **not in the set**, the CPU **cannot execute it**.

RISC-V is a specification, not a chip and not a language.

It says -

“If you build a CPU that claims to be RISC-V, it must understand these instructions and behave exactly this way.”

What about RISC-V Assembly?

RISC-V Assembly is:

- A **human-readable representation** of RISC-V instructions
- One-to-one mapping with machine code

Example:

ADD x1, x2, x3

Internally becomes

0000000 00011 00010 000 00001 0110011

The CPU only sees **binary**, not text.

So firmware:

Is **written in C / C++** → Compiled into **RISC-V machine instructions** → Executed by a **RISC-V** CPU

Why can't we call RISC-V a programming language?

- No variables
- No data types
- No loops (only jumps)
- No functions (only calling conventions)
- No memory safety
- No abstractions

It is a hardware control language, not a human problem-solving language

In Short: **RISC-V is not a programming language; it is an instruction set architecture that defines the exact machine instructions a CPU understands, and all firmware must be compiled into those instructions to run on a RISC-V processor.**

Registers

What are Registers?

Since Registers are hardwares which stores the data bits, how does it get an address ? Where is the address stored ?